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Low Profile Dual Spiral-Loop Antenna over Electromagnetic Band-gap Ground Plane for Circular Polarization

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1. Introduction

Electromagnetic band-gap (EBG) structures exhibit unique electromagnetic properties that have led to a wide range of applications in antenna and propagation fields [1], [2]. There are two major advantages associated with EBG ground planes. First, such structures exhibit the possibility of creating a perfect magnetic conductor (PMC) because of their in-phase reflection phase characteristics. This feature can cause efficient radiation for antennas laid adjacent to the EBG ground plane [3]. Second, these structures forbid the propagation of electromagnetic waves in a certain frequency band. Therefore, they can be used to block surface waves that usually corrupt antenna performance [4]. There have been efforts for designing low profile antennas with circular polarization using a mushroom-like EBG surface. A monopole curl antenna [5] and a square spiral antenna above a mushroom-like EBG surface [6] have been studied for circular polarization. In this paper, a low profile circular polarized antenna is designed using an EBG ground plane. The investigated antenna shows 8% axial ratio bandwidth (≤ 3 dB) and 7.8% return loss bandwidth (≤ -10 dB) with centre frequency of 2.4 GHz. In comparison with PEC ground plane, the total thickness of the structure is reduced 60%.

2. Antenna Structure

Previously, a dual rhombic-loop antenna above a PEC ground plane has been investigated [7]. Also, a dual rectangular-loop antenna with a series feed configuration has been developed for wideband circular polarization as well as good impedance matching [8]. In a dual loop antenna, two air gaps are located symmetrically with respect to the feed point on each loop. Proper position of gaps results in wideband circular polarization. Usually, a PEC ground plane is used to obtain a unidirectional radiation.

As shown in Fig. 1, a dual spiral-loop antenna consists of two spiral loops which are etched on the two opposite interfaces of a thin substrate with dielectric constant of $\varepsilon_{r1} = 2.94$ and thickness of $t_1 = 0.508$ mm. The two spiral loops are symmetrical with respect to the centre point. The thin substrate is located at a height of h above a ground plane. We design the dual spiral-loop antenna for the operating frequency of 2.4 GHz. The parameters of this antenna are as below:

$$l = 41.7 \text{ mm},\ l_1 = 30.1 \text{ mm},\ l_2 = 39.7 \text{ mm},\ v = 31.8 \text{ mm},\ d = 10 \text{ mm},\ s = 8 \text{ mm}. \quad (1)$$

The dual spiral-loop antenna is fed by an equivalent unit delta voltage source at the centre of the structure. The simulations are carried out using IE3D software for obtaining the radiation characteristics of antenna.

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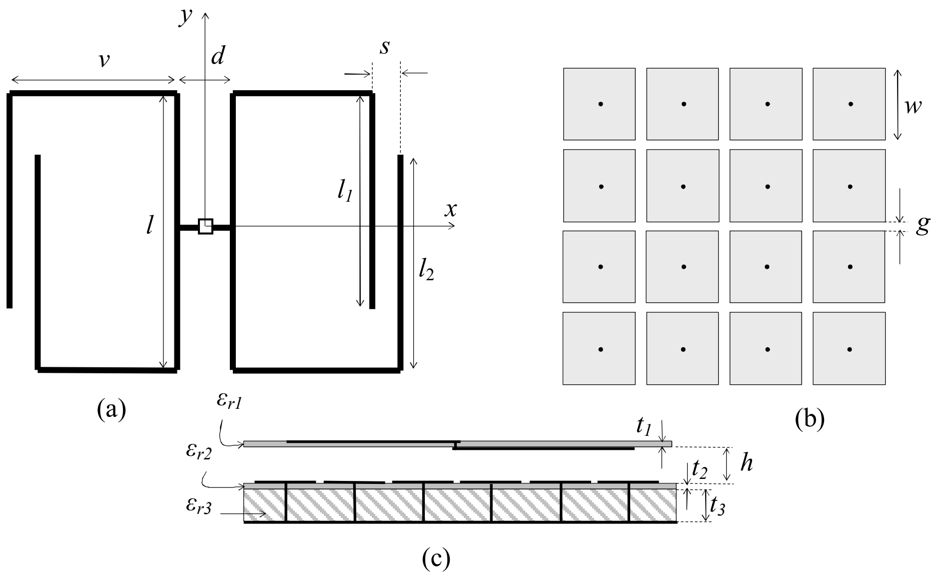


Figure 1: (a) Dual Spiral-loop Antenna with Series Feed (b) Mushroom-like EBG Ground Plane (c) Cross Section of the Antenna above the EBG Ground Plane.

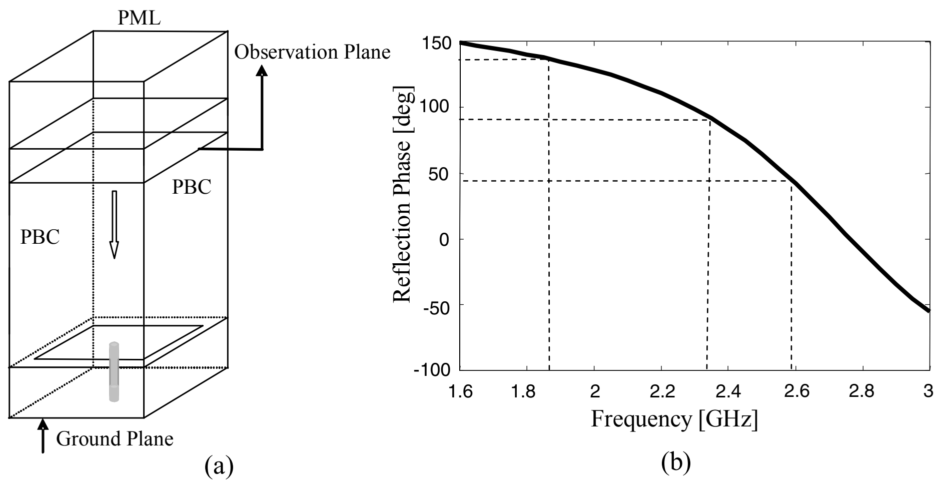


Figure 2: (a) Model for Calculation of Reflection Phase of a Periodic Surface (b) Reflection Phase of the Designed EBG Surface

3. Mushroom-like EBG Design

Studies on mushroom-like EBG surfaces show that these structures typically have PMC-like behavior at certain frequency band. The effect of each parameter of a square patch mushroom-like EBG surface on the central frequency and bandwidth of reflection phase has been investigated [3]. Reflection phase of a periodic surface can be computed using a unit cell with periodic boundary conditions [3], [9]. Fig. 2a shows the model for computing the reflection phase of a periodic surface. It is shown that the frequency region where the EBG surface has a reflection phase in the range $90° \pm 45°$ is very close to the input-match frequency band of a wire antenna placed over the EBG surface [3]. The operating frequency of the antenna is 2.4 GHz and it has good matching in the frequency band of 2.3-2.5 GHz. A mushroom-like EBG surface with parameters given in Table 1 is designed as a ground plane. The reflection phase of the EBG structure is illustrated in Fig. 2b. The surface reflection phase is between 45° and 135° in the frequencies range of 1.85-2.58 GHz. This frequency range covers the antenna bandwidth.

Table 1: Parameters of the EBG Surface Designed for the Dual Spiral-loop Antenna Ground Plane

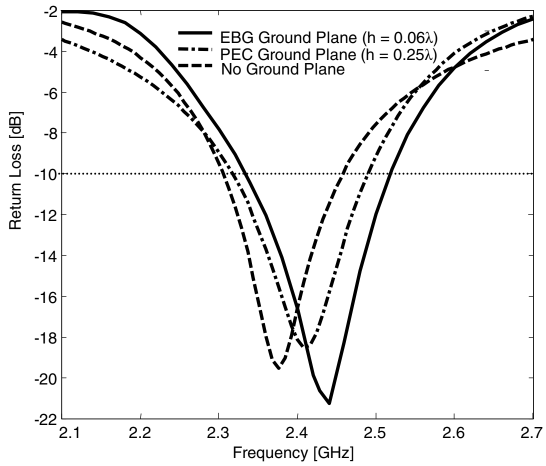
t_2	t_3	ε_{r2}	ε_{r3}	w	g
5 mm	0.5 mm	1.07	2.2	18 mm	0.5 mm

4. Simulation Results

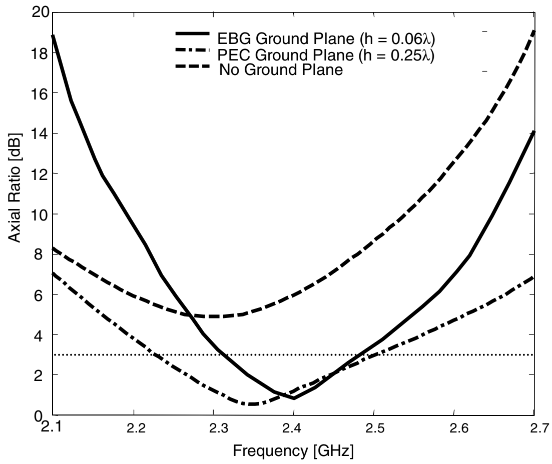
In this section, the full-wave IE3D software is used to compute main characteristics of the antenna, i.e. return loss, axial ratio and gain. Each characteristic of the antenna is investigated in three different cases. First, the antenna is placed at a distance of 0.06λ above the designed EBG surface. Second, a PEC ground plane is used. For good input-matching of the antenna, the antenna is placed at 0.25λ above its ground plane. Finally, the antenna performance is investigated when there is no ground plane. Fig. 3a illustrates the return loss of the antenna versus frequency. As shown in this figure, in all three cases good impedance matching near the centre frequency of 2.4 GHz is obtained. Return loss bandwidth (≤ -10 dB) of the antenna for the EBG ground plane, PEC ground plane and no ground plane cases are 7.8%, 7.1%, 6.7%, respectively. It should be noted that, in comparison with the PEC ground plane, using an EBG ground plane results in 60% reduction of the total structure thickness, while providing the same return loss bandwidth.

Fig. 3b illustrates the axial ratio of this antenna for the three cases. When there is no ground plane, the antenna does not provide a circular polarized radiation. When an EBG or PEC ground plane is located at a proper distance from the antenna, circular polarized radiation is obtained. The axial ratio bandwidth of the antenna for EBG and PEC ground plane cases are 8% and 12.2%, respectively. The antenna above PEC ground plane has larger axial ratio bandwidth. However the common frequency band in which the antenna has both good input-matching and circular polarized radiation is the same for both cases.

Fig. 4 exhibits the gain of the antenna for the three cases. As expected, using a PEC or EBG ground plane results in more than 3 dB gain increment. The antenna above EBG ground plane has a gain of about 9.2 dBi at the centre frequency of 2.4 GHz. The gain of the antenna above PEC is about 9.5 dBi.



(a)



(b)

Figure 3: The Dual Spiral-loop Antenna Characteristics (a) Return Loss (b) Axial Ratio

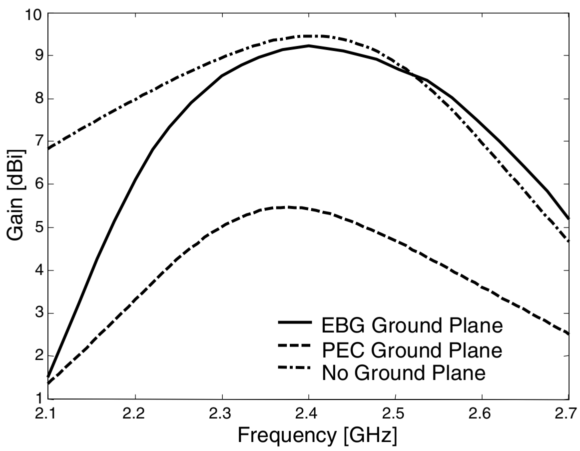


Figure 4: Gain of the Dual Spiral-loop Antenna

5. Conclusions

A circular polarized dual spiral-loop antenna has been investigated for a low profile design. Performance of this antenna when it is placed at a distance of 0.06λ above a well-designed EBG surface is studied. Also, the antenna performance using PEC ground plane and without any ground plane is presented. It is shown that the total thickness of the antenna structure is reduced 60% when an EBG surface is used as a ground plane. An axial ratio bandwidth of 8% and a return loss bandwidth of 7.8% are achieved with the proposed low profile structure.

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